PROGRESS IN THE USE OF CONTROLLED ATMOSPHERES IN ACTUAL FIELD SITUATIONS IN THE UNITED STATES

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ABSTRACT

Field research on the use of carbon dioxide (CO_2) for stored product insect control in the United States in the last 3 years is described. Minor efforts were made in sealing the storage structures studied and in 7 tests in upright concrete silos or welded steel bins containing wheat, maize, rice or sorghum the amount of CO_2 used/1,000 metric tonnes (t) grain ranged from 3.1 to 4.5 t. However, treatment costs/t of grain ranged from 0.23 to 0.39 U.S. $ because of the availability and low costs associated with CO_2 marketing in this country.

Additional studies on the use of CO_2 in farm storage situations and in rail hopper cars containing flour are also described. The future of the use of CA in the U.S. is discussed.

INTRODUCTION

Since the last meeting in Rome (Shejbal, 1980) on the subject of controlled atmospheres (CA) there has been an increased interest on the use of this residue-free insect-control technique for pests of grain and oilseeds in storage in the United States (U.S.). This interest cannot be described as an all-out conversion from the use of conventional fumigants to the use of CA. Rather, it can be considered as an inquiry by large grain and oilseed handlers into the effectiveness of the technique with particular emphasis being placed on the economics of the treatment when compared to the costs of using conventional fumigants. This interest is possibly also motivated by the realization that the U.S. Environmental Protection Agency (EPA) may prohibit the use of liquid fumigants containing carbon tetrachloride and methyl bromide for grain treatment in the future in the U.S. This would leave the grain industry with only hydrogen phosphide (PH_3) produced by aluminium or magnesium phosphide formulations for the fumigation of grain or oilseeds in post-harvest situations and with CA for treatment of these commodities.

Laboratory and field research conducted by the U.S. Department of Agriculture has shown that carbon dioxide (CO_2) is the CA of choice for use in situations where little or no attempts are made to seal the storage structure prior to treatment. CO_2 is effective in controlling storage pests at concentrations of 35% or more (Jay, 1971, 1980; Jay and Pearman, 1973; Jay et al. 1970). Although CO_2 is more effective at concentrations of ca. 60% for most storage pests,it can be allowed to fluctuate in the range of from 35 to 100% and insect control can be achieved. The exposure time needed to obtain high levels of insect control is a function of CO_2 concentration, temperature, grain moisture content, and the species and life stages of the insects which are infesting the grain or oilseeds (Bailey and Banks, 1980; Jay, 1984a,b). Current recommendations state that a concentration of from 45 to 60% CO_2 should be attained and maintained for 5 to 6 days at temperatures above 27^oC; for 10 to 14 days at a temperature at or above 21^oC and for 21 to 28 days at temperatures at or above 16^oC (Jay, 1984a). However, reluctance is encountered when these exposure times are suggested for use in cooperative studies with large grain processors since there is a general feeling that these exposure times are too long when the CO_2 treatment is compared with a PH_3 treatment. Therefore, most field studies conducted in this country have been for a 4-day period after a CO_2 concentration of ca 60% is attained in a storage structure. These treatments generally result in ca 95% control of natural or artificial insect infestations in the commodity being treated.

The U.S. EPA in 1980 granted an exemption from tolerance (approval for use) for the use of CO_2, nitrogen and combustion product gas (effluent from a CA generator) for all raw agricultural products (U.S. Federal Register 45, pp. 75663-64, Nov., 1980) and in 1981 for the use of these treatments on processed agricultural products (U.S. Federal Register 46, pp. 32865-66, June, 1981). This approval has stimulated some companies which produce CO_2 to attempt to introduce their product for use in stored-product insect control to the grain and oilseed industry. This paper describes some of the commercial scale tests that have been conducted in the last 3 years.

METHODS AND MATERIALS

Treatment of cylindrical grain storage bins

Silo and construction material, bin dimensions, commodity and amount of grain and its temperature are shown in Table 1. Trials 1 to 7 were conducted in terminal elevators or inland terminals located in Texas and trials 8 and 9 were conducted in Harvestore$^{(R)}$ bins located on a South Carolina farm. Harvestore bins are fiberglass lined steel bins generally used for the storage of silage.

CO_2 was supplied from pressurized tanks of 3.6 t, 5.4 t, or 10.9 t capacity and were equipped with suitable vaporization equipment. The CO_2 was introduced from the bottom of the bins in trials no. 2, 3, and 8 and from the top in the other trials (Table 1).

Table 1 - Bin type and dimensions and amount and temperature of the commodity in tests on the application of CO_2 to control insects.

Trial No.	Bin Type	Bin Dimensions (m) Height	: Diameter	Commodity	Amount Of Grain (t)	Temperature Range (C°)
1	Concrete	33.0	7.6	Wheat	1088	31 - 34
2	Welded Steel	12.8*	28.7	Wheat	5442	32 - 36
3	Welded Steel	12.8*	28.7	Wheat	5388	**
4	Concrete	37.0	7.4	Sorghum	1224	27 - 32
5	Concrete	37.0	7.4	Rice	1033	21 - 27
6	Concrete	**	**	Sorghum	726	**
7	Concrete	**	**	Maize	812	**
8	Harvestore			Wheat	381	30 - 35
9	Harvestore			Wheat	163	30 - 35

* Height of the wall to top cone.
** Data not available

Samples of grain were taken in trials no. 1, 8 and 9 to determine the percent reduction in emergence (% RIE) of adults which was caused by the treatments. In addition caged laboratory immature mixed-age cultures of Rhyzopertha dominica (F.) and Sitophilus oryzae (L.) were used for bioassay in trials no. 2, 4, 5, 6 and 7. The amount of CO_2 used in the purge and maintenance phases of the treatments was recorded from flow meters or from gauges installed in the supply tank. CO_2 concentrations were observed in gas samples taken from several locations in the silos.

Treatment of rail hopper-cars containing flour with dry ice

Four hopper-type rail cars equipped for the exclusive delivery of 77 t each of flour from the mill to bakeries located in the U.S. were modified for the tests. They were equipped with gas sampling lines and caged Tribolium confusum J. du Val. at depths of 0.6, 1.8 and 3.4 m (Ronai and Jay, 1982). The hopper cars were then filled with ca 77.1 t of flour. After filling, either 91 or 181 kg of dry ice pellets (small extruded pieces of solid CO_2) and 91 kg of dry ice blocks contained in cloth bags were pushed down into the bulk of flour in each car. The cars were shipped from the mill, located in Ohio, to a bakery located in Georgia. The length of the treatment (time from loading and applying the dry ice to unloading) was 10 to 11 days and the flour temperature was 33°C at loading and 24° to 28°C at the time they were unloaded.

RESULTS

CO_2 Application in Grain Storage Structures

Table 2 shows that the amount of CO_2 used during the purge phase in these tests varied from 32 to 158 kg. CO_2/h/1,000 t grain and during the maintenance phase from 13 to 52 kg. CO_2/h/1,000 t grain. This variation in the application rate during the purge phase was due to the duration of the CO_2 application, the CO_2 vaporizer delivery capacity and the size of the hose used to convey the CO_2 gas into the bin. The variation in the application rate during the maintenance phase was dependent on the gastightness of the experimental bins and the attempt to maintain the predetermined CO_2 concentration. The welded steel bins used in Trials 2 and 3 were more gastight than the concrete bins and consequently required lower maintenance rates. Trials conducted on Harvestores (Trials 8 and 9, Table 1) resulted in excessive usage of CO_2 (12.2 t CO_2/1,000 t of grain) due to equipment failure. Therefore, these results were not incorporated in Table 2.

CO_2 application time during the purge phase was dependent on the application rate chosen to attain the predetermined CO_2 concentration and was based on leak rates and the capacity of the vapourization equipment. However, the application time during the maintenance phase was kept in the range of 72 - 90 h (Table 2) to maintain an effective lethal CO_2 concentration for insect control.

Table 2 - CO_2 usage rate, application time, concentrations attained, and estimated cost of the CO_2 used to control insects (Trial numbers as identified in Table 1).

Trial No.	CO_2 application (kg CO_2/h/1000 t)		CO_2 application time (h)		Concentration (% CO_2) attained and maintained	Delivery Cost $US/t CO_2	Efficiency t CO_2/1000 t of grain	Cost $US/t of grain
	Purge	Maintenance	Purge	Maintenance				
1	84-125	32-52	6	90	60±10	73	3.2	0.23
2	32	14	88	80	80±10	73	4.0	0.29
3	33	13	72	72	80±10	73	3.3	0.24
4	56-102	34-39	17	79	60±10	77	4.2	0.32
5	158	38	8	88	60±10	73	4.5	0.33
6	58	25	18	78	80±10	88	4.4	0.39
7	*	*	*	*	60±10	88	3.1	0.27
						Mean	3.8	0.30
						SE ±	0.23	0.021

* Data not available

The CO_2 concentrations maintained during the maintenance phase varied from 50 to 90%.

Costs of Treatment

Cost of CO_2 at delivery for application on site, varied from $US 73 to 88/t CO_2 in trial nos. 1-7 (Table 2). However, for trials 8 and 9 (Table 1) the required CO_2 was supplied at a delivery cost of $ US 221/t. This high delivery cost was due to the low projected yearly use rate on the farm.

The efficiency of CO_2 usage expressed as t CO_2/1,000 t of grain for the first 7 trials are shown in Table 2. Accordingly the mean CO_2 usage was 3.8 t CO_2/1,000 t of grain with a standard error representing the variation under the described trial conditions as $\pm$ 0.23. Based on the CO_2 cost at delivery and the amount of CO_2 used, the mean treatment cost was $ US 0.30/t of grain.

Efficacy of CO_2 Treatment to Control Insects

Results obtained from treatment of wheat in an upright concrete silo (Trial no. 1) are shown in Table 3. This table shows that after a comparison of the pre- and post-treatment samples there was a 99% RIE of the natural population after the samples were incubated at 26°C for 60 days. Carbon dioxide concentrations in the basement under the silo did not exceed 0.5% (TLV value for an 8-h day) at any time during the test. During outloading, which was conducted 24 h after completion of the treatment, CO_2 concentration reached 0.8% for 21 h and then dropped below 0.5% for the remainder of the outloading period.

Table 3 - Mean number of alive insects from naturally infested wheat samples (1 kg) and percent reduction in emergence (% RIE) of adults recorded on Trial no. 1.

Days After Treatment	Mean number of alive insects per sample		% RIE
	Pretreatment	Posttreatment	
3	22	0	100
15	63	20	68
30	215	10	95
60	1,227	6	99

Treatment of wheat in a welded steel bin (Trial no. 2) resulted in 98.2 % RIE of adults from the immature stages of S. oryzae and 100% of R. dominica. These insects were not exposed to high concentrations of CO_2 except during the last 80 h of the treatment since the CO_2 which was applied from the bottom did not reach the top of the bin in high concentrations until 88 h after the initiation of the purge.

Treatment of sorghum in an upright concrete silo was carried out in Trial no. 4. The bioassay conducted on the mixed aged immature S. oryzae and R. dominica resulted in 99% RIE and 97% RIE of adults, respectively at the end of the treatment. However, since these insects were in the headspace of the silo and were exposed to high CO_2 concentrations during the purge and subsequent maintenance phases of the test, these results are considered inconclusive.

Treatment of rough rice in an upright concrete silo (Trial no. 5) showed that mortality of the insects exposed to this treatment was 100% while tests with sorghum and maize (Trials no. 6 and 7) indicated that the % RIE of caged, mixed age immature S. oryzae after treatment was 98.5.

Despite the high treatment costs of farm stored wheat (Trials no. 8 and 9, Table 1) the results of the treatments were effective. Table 4 shows that a 95% RIE was obtained in samples taken from the top and a >99% RIE was obtained in samples (1 kg) taken from the bottom at the 60 days post-exposure observation of the grain taken from the 381-t bin (Trial no. 8).

Table 4 - Treatment of 381 t farm stored wheat (Trial no. 8, Table 1). Number of alive insects from naturally infested wheat samples and % RIE of adults resulting from the CO_2 treatment.

Days After Treatment	Mean No. Insects/Sample Pretreatment	Mean No. Insects/Sample Posttreatment	% RIE
	Bottom Samples		
4	10	1	93
30	28	8	73
60	402	19	95
	Top Samples		
4	2	0	100
30	7	0.3	96
60	29	0.1	> 99

Table 5 shows that similar results were obtained in the smaller bin containing 163 t of wheat (Trial no. 9). In this bin the % RIE of adults was >99 at both the 30 and 60 day post-treatment examinations.

Table 5 - Treatment of 163 t farm stored wheat (Trial no. 9, Table 1). Number of alive insects from naturally infested wheat samples and % RIE of adults resulting from the CO_2 treatment.

Days After Treatment	Mean No. Insects/Sample		% RIE
	Pretreatment	Posttreatment	
4	48	22	54
30	150	1	>99
60	1,111	2	>99

Treatment of rail hopper-cars containing flour with dry ice

Table 6 presents observed CO_2 concentrations in one of the hopper cars before it left the mill (18 to 41-h readings) and observed CO_2 concentrations 10 days after the car was filled and shipped to the bakery. The dry ice changed to gas slowly in the first 41 h of treatment but an even distribution of from 31 to 40% was observed 10-days after filling. Readings for CO_2 concentration or distribution were not taken while the cars were in transit.

Table 6 - Carbon dioxide concentrations in hopper car S90143 containing 77 t flour and treated with 181 kg dry ice.*

Sample Depth (m)	% CO_2 at indicated time after treatment**			
	18 h	25 h	41 h	10 days
0.6	30	43	45	31
1.8	8	18	23	38
3.4	2	6	17	40

* From Ronai and Jay, 1982.

** Hopper car was in-transit between 41-h after application and arrival at destination 10-days later.

However, mortality of T. confusum larvae during the exposure period ranged from 95.2 to 99.1% indicating that the treatment was effective (Table 7).

Table 7 - Mortality of T. confusum larvae in flour contained hopper cars during a 10 or 11 day in-transit exposure.*

Hopper Car No.	CO_2 used (kg)	% Mortality
1	181	99.1
2	181	99.1
3	181	95.2
4	272	98.3

* From Ronai and Jay (1982)

This table also shows that mortality was not increased in hopper car number 4 when an additional 91 kg of dry ice pellets were added when compared with 2 of the other 3 cars which did not have the additional pellets and was only slightly higher than that observed in car no. 3.

Costs for dry ice for the three cars treated at the rate of 181 kg/car was $24 per car while the cost for a PH_3 treatment was estimated to be $17. However, labor costs involved in the 1.5 h aeration of a car treated with PH_3 prior to unloading was estimated to be $25 so the net savings per car when the dry ice was used was estimated to be $18. Also, cars treated with CO_2 could be unloaded immediately while cars treated with PH_3 would have to stand at the unloading point during aeration. Thus, the use of CO_2 would result in a much faster turnaround of the cars.

DISCUSSION

Carbon dioxide use per ton of grain in these studies was very high when compared to the amount used in well-sealed Australian storages (Banks, et al., 1980). The gastightness of the experimental bins was not determined, but they were suspected to be low. Despite the low level of gastightness of these storage structures, the CO_2 application costs/t of grain were low (Table 2). This is obviously because of the low delivery cost of CO_2 in most situations in the U.S. This low cost, which in many cases results in treatment costs for CO_2 being competitive with costs for the use of conventional fumigants, may cause large grain and oilseed companies to be reluctant to attempt any extensive sealing of their storage structures prior to the use of this treatment. However, studies on the economics of sealing the discharge areas of upright concrete silos, where the majority of the CO_2 is lost during treatment, are to be initiated so that gas loss can be partially reduced.

The fact that large grain companies in this country are interested in this technique is encouraging. The rice industry in particular, is adopting this technique and, by the end of 1983, five large rice processors located in the states of Texas, Arkansas and Louisiana are planning to have CO_2 vessels located on their premises for routinely treating rough and processed rice with CO_2. There is also considerable interest in the use of CO_2 for control of insects attacking stored tree nuts and groundnuts (peanuts) indicating that processors of agricultural commodities having a high value per ton, as compared to cereals, may be the first to use this technique on a large scale in the U.S.

The use of CO_2 in on-farm storage situations presents additional problems as far as treatment costs are concerned. Although ca. 60% of the wheat and feed grains are stored on-farm in the U.S., the logistics of transporting liquid CO_2 to these areas appear to be costly (\$221/t CO_2) for delivery in the one on-farm test reported above. Obviously, the use of gaseous CO_2 in on-farm situations will involve either sealing to very rigorous gas-tight specifications or development of some other form of CA treatment before the use of this technique can be competitive with conventional fumigants.

The use of CO_2 and other CA treatments in the U.S. need not be restricted to stored grain. The effectiveness of CO_2 when used in rail hopper cars containing flour for insect control can be expanded to other processed agricultural products in both static and in-transit situations. Also, the technique could be expanded in the U.S. for use with many agricultural products in in-transit situations such as truck-ship type containers, barges and ocean going ships. More research in these areas is needed to provide the grain industry with techniques and information to determine situations where CA is advantageous over alternative insect control methods.

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